(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 126 415 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
22.08.2001 Bulletin 2001/34

(51) Int Cl.7: G06T 15/60

(21) Application number: 01301366.9

(22) Date of filing: 16.02.2001

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 17.02.2000 JP 2000039820
24.01.2001 JP 2001015757

(71) Applicant: Sony Computer Entertainment Inc.
Tokyo 107-0052 (JP)

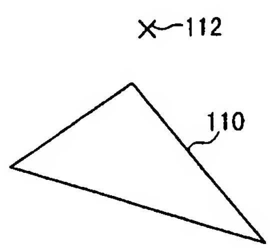
(72) Inventors:
- Hino, Akihiro, c/o Level-5 INC.
Fukuoka-shi, Fukuoka-ken 810-0041 (JP)
- Motomura, Kentaro, c/o Sony Computer
Tokyo 107-0052 (JP)

(74) Representative: Horner, David Richard
D Young & Co,
21 New Fetter Lane
London EC4A 1DA (GB)

(54) Image drawing method and apparatus

(57) A primary polygon (110) is processed to generate new secondary polygons (110a, 110b, 110c) utilizing a light source (112) as a base point. A front-side secondary polygon (110a) is selected from the secondary polygons (110a, 110b, 110c) and drawn in a blackish color by rendering and hidden surface removal utilizing Z-buffering. Then, backside secondary polygons (110b, 110c) are drawn by rendering and hidden surface removal utilizing Z-buffering such that the color (blackish color) of the secondary polygon (110a) is eliminated. That is, the eliminated portions of the secondary polygon (110a) become transparent.

FIG. 4A

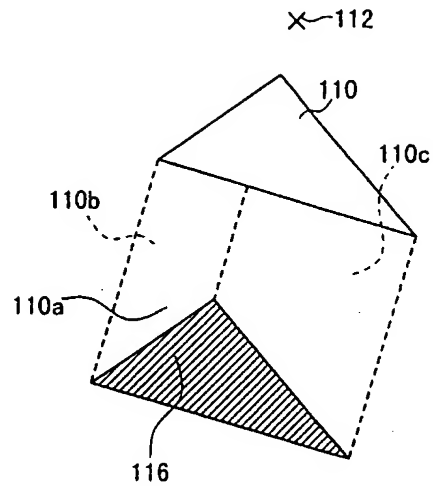


EP 1 126 415 A2

Printed by Jouve, 75001 PARIS (FR)

(Cont. next page)

FIG. 4D



Description

BACKGROUND OF THE INVENTION

Field of the Invention:

[0001] The present invention relates to an image drawing method, and an image drawing apparatus which make it possible to draw images of shadows produced by light emission from a light source, for example when based on a positional relationship of a plurality of objects generated by three-dimensional modeling such that shadow images of objects positioned near the light source are drawn on other objects positioned distantly from the light source. Further, the present invention relates to a recording medium which stores a program for carrying out such image processing, and the program itself.

Description of the Related Art:

[0002] In recent years, there has been a rapid advancement of computer graphics techniques such as hidden line removal, hidden surface removal, smooth shading, and texture mapping thanks to the dramatic development of hardware.

[0003] Generally, with the computer graphics techniques, images are generated by the following procedure. Firstly, a plurality of three-dimensional objects are generated by three-dimensional modeling. Then, rendering is performed by adding optical properties such as specular reflection, diffuse reflection, refraction, and transparency to the objects with the shading technique, by adding surface patterns to the objects, and by plotting images depending on surroundings such as a window and scenery reflections and ambient light.

[0004] It is difficult to perform a process of expressing a shadow of an object cast on another object positioned there-behined based on the layout of a light source and a plurality of objects. One rendering technique for performing the process is ray tracing. However, such a technique requires highly complicated calculations which put CPU or the like under heavy load. Another rendering technique for expressing a shadow utilizes a stencil buffer. However, the technique requires a stencil buffer as an additional mask (memory). Further, the technique requires a process of extracting an area corresponding to a shadow from the stencil buffer and a process of drawing semi-transparent polygons in a blackish color in the extracted area. Therefore, the number of the processes is increased.

[0005] If heavy load and complicated processes should be avoided such as for real time rendering, then it has heretofore been customary to approximate such a shadow with perspective projection onto a simple plane in a simple figure such as a circle.

SUMMARY OF THE INVENTION

[0006] Embodiments of the invention seek to provide an image drawing method, and an image drawing apparatus which make it possible to draw shadow images of a plurality objects in a complicated positional relationship, and draw a shadow image of a complicated object without any difficulties. Embodiments of the present invention also seek to provide a recording medium which stores a program for carrying out such image processing of drawing a shadow image without any difficulties, and to provide the program itself.

[0007] According to the present invention, an image processing method of drawing a shadow image of at least one primary surface constituting a three-dimensional object comprises the steps of:

generating new secondary surfaces based on the primary surface utilizing a light source as a base point;
drawing a first image of a front-side secondary surface selected from the secondary surfaces; and
drawing a second image of a back-side secondary surface selected from the secondary surfaces,
wherein the second image is drawn such that the first image is partially eliminated by the second image, thereby generating the shadow image of the primary surface.

[0008] Further, according to the present invention, an image drawing apparatus comprises means for drawing a shadow image of at least one primary surface constituting a three-dimensional object, the means for drawing a shadow image comprising:

means for generating new secondary surfaces based on the primary surface utilizing a light source as a base point;
means for drawing a first image of a front-side secondary surface selected from the secondary surfaces; and
means for drawing a second image of a back-side secondary surface selected from the secondary surfaces,
wherein the second image is drawn such that the first image is partially eliminated by the second image, thereby generating the shadow image of the primary surface.

[0009] Further, according to the present invention, a recording medium records a program and data for use of an image drawing apparatus for drawing image data in an image memory and outputting the image data drawn in the image memory to a monitor so that the outputted image data can be displayed on the monitor, the program comprising the steps of;

generating new secondary surfaces based on the

primary surface utilizing a light source as a base point;
drawing a first image of a front-side secondary surface selected from the secondary surfaces; and
drawing a second image of a back-side secondary surface selected from the secondary surfaces,
wherein the second image is drawn such that the first image is partially eliminated by the second image, thereby generating the shadow image of the primary surface.

[0010] Further, according to the present invention, a program is readable and executable by a computer for use of an image drawing apparatus for drawing image data in an image memory and outputting the image data drawn in the image memory to a monitor so that the outputted image data can be displayed on the monitor, the program comprising the steps of;

generating new secondary surfaces based on the primary surface utilizing a light source as a base point;
drawing a first image of a front-side secondary surface selected from the secondary surfaces; and
drawing a second image of a back-side secondary surface selected from the secondary surfaces,
wherein the second image is drawn such that the first image is partially eliminated by the second image, thereby generating the shadow image of the primary surface.

[0011] In embodiments of the present invention, it is preferable to utilize Z-buffering in performing hidden surface removal.

[0012] Accordingly, it is possible to easily generate shadow images of a plurality of objects in a complicated positional relationship, or generate a shadow image of an object having a complicated shape without using a stencil buffer. Since a shadow image is generated when the second image for partially eliminating the first image is drawn, it is no more necessary to draw semi-transparent polygons in a blackish color in the last step. Therefore, the number of the processes can be effectively decreased. In particular, three-dimensional information concerning an object on which a shadow is projected is not necessary in drawing a shadow image. That is, information concerning two-dimensional images in an image memory and Z-buffer values for respective pixels of the two-dimensional images are only needed.

[0013] The primary surface may be drawn by rendering and hidden surface removal. Further, the first and second images of the secondary surfaces may be drawn by rendering and hidden surface removal.

[0014] Further, according to an embodiment of the present invention, a series of drawing processes comprising drawing of the primary surface, generation of the secondary surfaces, and drawing of the first and second images of the secondary surfaces are performed for every primary surface constituting the three-dimensional object, thereby drawing an image of the three-dimensional object and a shadow image of the three-dimensional object.

[0015] Further, according to an embodiment of the present invention, when there are a plurality of primary surfaces constituting at least one three-dimensional object, the series of drawing processes are performed for every primary surface in order of distance from the remotest primary surface from the light source such that a shadow image of a primary surface is drawn on another primary surface.

[0016] Further, according to another embodiment of the present invention, when there are a plurality of three-dimensional objects, the series of drawing processes are performed for every three-dimensional object in order of distance from the remotest three-dimensional object from the light source such that a shadow image of at least one three-dimensional object is drawn on another three-dimensional object.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The invention will now be described by way of example with reference to the accompanying drawings, throughout which like parts are referred to by like references, and in which:

FIG. 1 is a view showing an arrangement of an entertainment system according to the present embodiment;
FIG. 2 is a view showing an example of addressing of an image memory;
FIG. 3 is a view showing an image of a main character and a shadow image of the main character;
FIGS. 4A through 4D are views for explaining an example of generating a shadow image by image drawing means according to the present embodiment;
FIGS. 5A through 5D are views for explaining another example of generating a shadow image by the image drawing means according to the present embodiment;
FIG.6 is a functional block diagram of the image drawing means according to the present embodiment;
FIG. 7 is a flow chart showing a processing sequence (No.1) of the image drawing means according to the present embodiment; and
FIG. 8 is a flow chart showing a processing sequence (No. 2) of the image drawing means according to the present embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0018] An embodiment of an image drawing method, an image drawing apparatus, a recording medium, and a program according to the present invention as applied

to an entertainment system for executing various programs (hereinafter simply referred to as the entertainment system according to the present embodiment) will be described with reference to drawings.

[0019] As shown in FIG. 1, the entertainment system 10 according to the present embodiment basically comprises an entertainment apparatus 12 for executing various programs, a memory card 14 detachably connected to the entertainment apparatus 12, a manual controller 16 detachably connected to the entertainment apparatus 12, and a monitor (display) 18 such as a television receiver which is supplied with video and audio signals from the entertainment apparatus 12.

[0020] The entertainment apparatus 12 reads a program recorded in a mass storage medium such as an optical disk 20 such as a CD-ROM or the like, and executes a game, for example, based on the program depending on commands supplied from a user, e.g., a game player, via the manual controller 16. The execution of the game mainly represents controlling the progress of the game by controlling the display of images and the generation of sounds on the monitor 18 based on manual input actions entered from the manual controller 16.

[0021] As shown in FIG. 1, the entertainment apparatus 12 generally comprises a control system 200, a graphic generating system 204 connected to the control system 200 via a system bus 202, a sound generating system 206 connected to the control system 200 via the system bus 202, and an optical disk control system 208 connected to the control system 200 via the system bus 202. A communication controller 210 for controlling data to be inputted to and outputted from the manual controller 16 and the memory card 14 is also connected to the control system 200 via the system bus 202.

[0022] The manual controller 16 supplies commands (including manipulation data) from the user via the communication controller 210 to the entertainment apparatus 12. The optical disk control system 208 includes an optical disk drive 212 in which the optical disk 20 is loaded. The optical disk 20 may comprise a CD-ROM or the like as a specific example of a recording medium according to the present invention.

[0023] The control system 200 controls motions of characters displayed on the monitor 18 based on a program and data read from the optical disk 20 and commands supplied from the manual controller 16.

[0024] The control system 200 includes a micro processing unit (MPU) 220, a main memory 222, a peripheral device controller 224, a ROM 226, and a realtime clock (RTC) 228. The MPU 220 controls the entertainment system 12. The main memory 222 stores various programs to be executed and various data. That is, the main memory 222 at least stores a game program so that the game program can be executed on the main memory 222. The peripheral device controller 224 controls interrupts and direct memory access (DMA) data transfer. The ROM 226 stores various programs such as an operating system for managing the graphic system 204, the sound generating system 206, etc. Further, the ROM 226 stores information for controlling kernel or the like, and information for performing an OSD function.

[0025] The MPU 220 controls the entertainment apparatus 12 in its entirety by executing the operating system stored in the ROM 226. The MPU 220 may comprise a 32-bit RISC-CPU, for example.

[0026] When the entertainment apparatus 12 is turned on, the MPU 220 executes the operating system stored in the ROM 226 to start controlling the graphic generating system 204, the sound generating system 206, etc.

[0027] When the operating system is executed, the MPU 220 initializes the entertainment apparatus 12 in its entirety for checking its operation, and thereafter controls the optical disc control system 208 to execute an application program such as a game program recorded in the optical disk 20.

[0028] As the application program such as a game program is executed, the MPU 220 controls the graphic generating system 204, the sound generating system 206, etc. depending on commands entered from the user for thereby controlling the display of images and the generation of music sounds and sound effects.

[0029] The graphic generating system 204 comprises a vector operation unit 230 for performing floating-point vector operations required for geometry processing, an image processor 232 for generating image data under the control of the MPU 220 and outputting the generated image data to a monitor 18, e.g., a CRT, a graphic interface (GIF) 234 for serving as transfer paths between the MPU 220, the vector operation unit 230, and the image processor 232, and an image decoder 236 for decoding image data compressed and encoded by an orthogonal transform such as a discrete cosine transform.

[0030] The image processor 232 comprises a rendering engine 240, a memory interface 242, an image memory 244, and a display controller 246 such as a programmable CRT controller or the like.

[0031] The rendering engine 240 serves to render and store image data in the image memory 244 via the memory interface 242 based on a rendering command supplied from the MPU 220.

[0032] A first bus 248 is connected between the memory interface 242 and the rendering engine 240, and a second bus 250 is connected between the memory interface 242 and the image memory 244. Each of the first and second buses 248, 250 has a 128-bit width, for example, for allowing the rendering engine 240 to render and store image data in the image memory 244 at a high speed.

[0033] The rendering engine 240 is capable of rendering image data of 320 × 240 pixels or image data of 640 × 480 pixels according to the NTSC or PAL system on a real-time fashion, i.e., more than ten times to several ten times in 1/60 seconds to 1/30 seconds.

[0034] The image memory 244 is a unified memory

structure that is able to designate a texture rendering area and a display rendering area as the same area. For example, in FIG. 2, a frame buffer 244a, a Z-buffer 244b, and a texture buffer 244c are designated by logical addressing in the image memory 244, respectively. Alternatively, the Z-buffer may be separately designated in another memory by physical addressing.

[0035] As shown in FIG. 1, the display controller 246 writes texture data read from the optical disk 20 via the optical disk drive 212 or texture data generated in the main memory 222 via the memory interface 242 into the texture buffer 244c of the image memory 244, and reads image data stored in the frame buffer 244a of the image memory 244 via the memory interface 242 and outputs the read image data to the monitor 18 to display an image on its display screen.

[0036] The sound generating system 206 comprises a sound processing unit (SPU) 260 for generating music sounds, sound effects, etc. based on instructions from the MPU 220, and a sound buffer 262 for storing music sounds, sound effects, etc. generated by the SPU 260. Audio signals representing music sounds, sound effects, etc. generated by the SPU 260 are supplied to audio terminals of the monitor 18. The monitor 18 has a speaker 264 which radiates music sounds, sound effects, etc. generated by the SPU 260 based on the supplied audio signals.

[0037] The SPU 260 has an ADPCM (adaptive differential PCM) function for reproducing 16-bit sound data which has been encoded as 4-bit differential sound data by ADPCM, a reproducing function for reproducing waveform data stored in the sound buffer 262 to generate sound effects, etc., and a modulating function for modulating and reproducing the waveform data stored in the sound buffer 262.

[0038] The sound system 206 with these functions can be used as a sampling sound source which generates music sounds, sound effects, etc. based on the waveform data stored in the sound buffer 262 according to instructions from the MPU 220.

[0039] The optical disk control system 208 comprises an optical disk drive 212 for reproducing application programs and data recorded on the optical disk 20, a decoder 270 for decoding programs and data that are recorded with an error correcting code added thereto, and a buffer 272 for temporarily storing data read from the optical disk drive 212 so as to allow the data from the optical disk 20 to be read at a high speed. A CPU 274 is connected to the decoder 270.

[0040] Sound data recorded on the optical disk 20 which is read by the optical disk drive 212 includes PCM data converted from analog sound signals, in addition to the ADPCM data.

[0041] The ADPCM data, which is recorded as 4-bit differential data of 16-bit digital data, is decoded by the decoder 270, supplied to the SPU 260, converted thereby into analog data, and applied to drive the speaker 264.

[0042] The PCM data, which is recorded as 16-bit digital data, is decoded by the decoder 270 and then applied to drive the speaker 264.

[0043] Next, a characteristic function of the entertainment system 10 according to an embodiment of the present invention will be described with reference to FIGS. 3 through 8.

[0044] In FIG. 3, for example, an object as a main character 100 in a role playing game is generated by a three-dimensional modeling technique. The characteristic function of the entertainment system 10 is to draw a shadow image 102 of the main character 100 on the background or other objects based on a positional relationship between the main character 100 and a light source.

[0045] Various objects such as the main character 100 are used in the role playing game. Each of the objects is made up of a plurality of polygons (primary polygons). The characteristic function of the entertainment system 10 is performed by rendering the plurality of primary polygons one by one for drawing the shadow image 102 on the background or other objects.

[0046] The processing sequence of drawing a shadow image of a primary polygon selected from the plurality of primary polygons is described below.

[0047] Firstly, the selected primary polygon is drawn by rendering and hidden surface removal utilizing Z-buffering (depth buffering). Next, new secondary polygons corresponding to the primary polygon are generated utilizing a light source as a base point. Thereafter, visible secondary polygons, i.e., the surfaces which are visible from a viewing position (camera position) in the world coordinate system (hereinafter also referred to as the front-side secondary polygons) are subjected to rendering and hidden surface removal utilizing Z-buffering. Then, invisible secondary polygons, i.e., the surfaces which are not visible from the viewing position (hereinafter also referred to as the back-side secondary polygons) are subjected to rendering and hidden surface removal utilizing Z-buffering. It is to be understood that various light sources such as a point light source and a surface light source can be used as the light source.

[0048] The above-described processing sequence will be described more specifically with reference to FIGS. 4A through 4D.

[0049] As shown in FIG. 4A, it is assumed that a triangular primary polygon 110 is positioned above a surface (for example, a ground surface as a background). Firstly, the primary polygon 110 generated by rendering and hidden surface removal utilizing Z-buffering is drawn in the image memory 244.

[0050] Next, as shown in FIG. 4B, new secondary polygons 110a through 110c corresponding to the primary polygon 110 are generated utilizing a light source 112 as a base point. Specifically, three segments (lines) 114a through 114c constituting the primary polygon 110 are subjected to a perspective transformation to the ground surface. Then, the three secondary polygons

110a through 110c are generated based on coordinate values corresponding to vertices of the primary polygon 110 (vertices of the three segments 114a through 114c) and coordinate values corresponding to vertices of the transformed primary polygon projected on the ground surface.

[0051] Thereafter, as shown in FIG. 4C, the front-side secondary polygon 110a is subjected to rendering and hidden surface removal utilizing Z-buffering for drawing an image of the secondary polygon 110a. At this time, the image of the secondary polygon 110a is drawn in a blackish color.

[0052] Then, the back-side secondary polygons 110b, 110c are subjected to rendering and hidden surface removal utilizing Z-buffering for drawing images of the secondary polygons 110b, 110c. At this time, the images of the secondary polygons 110b, 110c are drawn such that the color (blackish color) of the front-side secondary polygon 110a is eliminated. That is, the eliminated portions of the front-side secondary polygon 110a become transparent.

[0053] By the above drawing processing sequence, a shadow image 116 of the primary polygon 110 is generated on the ground surface.

[0054] Next, the processing sequence of drawing a shadow image of the primary polygon 110 on another object (polygon, moving image, or still image) will be described with reference to FIGS. 5A through 5D.

[0055] In this example, as shown in FIG. 5A, it is assumed that there is a spherical object 120 in addition to the primary polygon 110. Further, it is assumed that the spherical object 120 is remotely positioned from the light source 112 in comparison with the primary polygon 110. That is, it is assumed that the shadow image of the polygon 110 is to be drawn on the surface of the spherical object 120.

[0056] Images of the primary object 110 and the spherical object 120 are drawn in the image memory 244 in order of distance from the remoter object from the light source 112a. That is, the spherical object 120 is drawn first. Thereafter, the primary polygon 110 is drawn in the image memory 244 after being subjected to rendering and hidden surface removal utilizing Z-buffering. Then, as shown in FIG. 5B, new secondary polygons 110a through 110c corresponding to the primary polygon 110 are generated utilizing a light source 112 as a base point.

[0057] Next, as shown in FIG. 5C, the front-side secondary polygons 110a is subjected to rendering and hidden surface removal utilizing Z-buffering for drawing an image of the secondary polygon 110a in a blackish color. At this time, Z-buffer values for respective pixels of the spherical body 120 and the Z-buffer values for respective pixels of the front-side secondary polygon 110a are compared with each other at portions where pixels of the spherical body 120 and pixels of the front-side secondary polygon 110a are overlapping with each other. If a Z-buffer value for a pixel of the front-side secondary polygon 110a is, for example, higher than a Z-buffer value for the corresponding (overlapping) pixel of the spherical body 120, the pixel of the front-side secondary polygon 110a is not drawn. That is, portions of the front-side secondary polygon 110a hidden by the spherical body 120 (pixels where the front-side secondary polygon 110a has the higher Z-buffer values) are not drawn. With the above process, as shown in FIG. 5C, an image showing the spherical body 120 partially cut away by the front-side secondary polygon 110a is generated.

[0058] Then, the back-side secondary polygons 110b, 110c are subjected to rendering and hidden surface removal utilizing Z-buffering for drawing images of the secondary polygons 110b, 110c such that the color (blackish color) of the front-side secondary polygon 110a is eliminated. At this time, as with the front secondary polygon 110a, the back-side secondary polygons 110b, 110c are drawn based on comparison between the Z-buffer values of the back-side secondary polygons 110b, 110c and the Z-buffer values of the spherical body 120. That is, portions of the back-side secondary polygons 110b, 110c hidden by the spherical body 120 are not drawn.

[0059] As shown in FIG. 5D, the blackish color of the front-side secondary polygon 110a is not eliminated by the back-side secondary polygons 110b, 110c at some portions where the back-side secondary polygons 110b, 110c are not drawn based on the comparison between the Z-buffer values of the back-side secondary polygon 110b, 110c and the Z-buffer values of the spherical body 120. That is, a shadow image of the primary polygon 110 projected on the surface (spherical surface) of the spherical body 120 is generated by the remaining portion of the front-side secondary polygon 112a drawn in the blackish color.

[0060] Next, an example of software (image drawing means 300) for carrying out the above-described characteristic function will be described with reference to FIGS 6 through 8.

[0061] The image drawing means 300 can be supplied from a randomly accessible recording medium such as an optical disk 20, a memory card 14 or the like to the entertainment apparatus 12. Alternatively, the image drawing means 300 can be downloaded via a network such as the Internet or downloaded via a satellite communication or the like to the entertainment apparatus 12. In the following explanation, it is assumed that the image drawing means 300 is supplied from an optical disk 20.

[0062] Specifically, the optical disk 20 is played back by the optical disk drive 212 to read the image drawing means 300 and the read image drawing means 300 is stored in the main memory 222 in the control system 200 of the entertainment apparatus 12 by a predetermined process. Thereafter, the image drawing means 300 is executed by the MPU 220 of the control system 200 of the entertainment apparatus 12.

[0063] As shown in FIG. 6, the image drawing means

300 comprises drawing order determining means 302, primary polygon drawing means 304, secondary polygon generating means 306, first secondary polygon drawing means 308, second secondary polygon drawing means 310, process determining 312, and image displaying means 314. The drawing order determining means 302 determines the order of drawing objects in order of distance from the remotest object from a light source 112. The primary polygon drawing means 304 draws a primary polygon (an element of an object) 110 according to the determined drawing order by rendering and hidden surface removal. The secondary polygon generating means 306 generates secondary polygons 110a through 110c corresponding to the primary polygon 110 utilizing the light source 112 as a base point. The first secondary polygon drawing means 308 draws a front-side secondary polygon 110a selected from the secondary polygons 110a through 110c by rendering and hidden surface removal. The second secondary polygon drawing means 310 draws back-side secondary polygons 110b, 110c selected from the secondary polygons 110a through 110c by rendering and hidden surface removal. The process determining means determines 312 whether or not each of the drawing processes has been finished or not. The image displaying means 314 outputs image data drawn in the image memory 244 to the monitor 18 so that the outputted image data can be displayed on the screen of the monitor 18.

[0064] Next, the processing sequence of the image drawing means 300 will be described with reference to flow charts shown in FIGS. 7 and 8.

[0065] It is assumed that positions of objects to be drawn by the image drawing means 300 are defined by the world coordinate system.

[0066] In Step S1 of FIG. 7, when the image drawing means 300 receives movement information indicating movements of objects, the image drawing means 300 rewrites the basic positions (coordinates in the world coordinate system) of moved objects.

[0067] Next, in Step S2, the image drawing means 300 sets a position of a light source 112. Then, in Step S3, the drawing order determining means 302 of the image drawing means 300 determines an order of drawing objects. Specifically, the drawing order determining means 302 determines the order based on the basic positions of the objects and the position of the light source 112 such that data of the objects are read in order of distance from the remotest object from the light source 112. That is, the objects are drawn in order of distance from the remotest object from the light source 112.

[0068] Then, in Step S4, the image drawing means 300 stores an initial value "0" in an index register i used to retrieve an object, thereby initializing the index register i.

[0069] Then, in Step S5, the image drawing means 300 reads data concerning the i-th object. Thereafter, in Step S6, the image drawing means 300 stores an initial value "0" in an index register j used to retrieve a primary polygon, thereby initializing the index register j.

[0070] Then, in Step S7, the primary polygon drawing means 304 reads data concerning the j-th primary polygon 110 from the i-th object data read in Step S5.

[0071] Then, in Step S8, the primary polygon drawing means 304 rewrites data concerning vertices of the j-th primary polygon 110 based on the basic position of the i-th object and optical information (the position of the light source 112, the type of the light source 112, or the like). Then, in Step S9, the primary polygon drawing means 304 draws an image of the j-th primary polygon 110 in the image memory 244 by rendering and hidden surface removal utilizing Z-buffering.

[0072] Then, in Step S10 of FIG. 8, the secondary polygon generating means 306 stores an initial value "0" in an index register k used to retrieve a segment, thereby initializing the index register k.

[0073] Then, in Step S11, the secondary polygon generating means 306 reads the k-th segment constituting the primary polygon 110 from the index register k for generating the k-th secondary polygon. Specifically, the secondary polygon generating means 300 performs a perspective transformation of the k-th segment to the ground surface utilizing the light source 112 as a base point. The k-th secondary polygon is generated based on the position of the k-th segment and the position of the transformed k-th segment, i.e., coordinates corresponding to vertices of the k-th segment and coordinates corresponding vertices to of the k-th segment projected on the ground surface.

[0074] In Step S12, the secondary polygon generating means 306 updates the value of the index register k to be incremented by 1. Then, in Step S13, the process determining means 312 determines whether secondary polygons for all of the segments constituting the primary polygon 110 have been generated or not. That is, it is determined that whether the value of the index register k is equal to or more than the number A of the segments constituting the primary polygon 110 or not.

[0075] If the value of the index register k is equal to or more than the number A of the segments constituting the primary polygon 110, the process determining means 312 determines that secondary polygons for all of the segments constituting the primary polygon 110 have been generated.

[0076] If the process determining means 312 determines that secondary polygons for all of the segments constituting the primary polygon 110 have not been generated, control passes back to Step S11 for generating another secondary polygon for the next segment. When secondary polygons for all of the segments constituting the primary polygon 110 are generated, control passes to Step S14. In Step S14, the first secondary polygon drawing means 308 draws an image of a front-side secondary polygon 110a in a blackish color in the image memory 244 by rendering and hidden surface removal utilizing Z-buffering.

[0077] Then, in Step S15, the second secondary polygon drawing means 310 draws images of the remaining back-side secondary polygons 110b, 110c in the image memory 244 by rendering and hidden surface removal utilizing Z-buffering. The images of the back-side secondary polygons 110b, 110c are drawn such that the color (blackish color) of the front-side secondary polygon 110a is eliminated.

[0078] In Step S16, the value of the index register j is incremented by 1. Then, in Step S17, the process determining means 312 determines whether all the primary polygons 110 constituting the i-th object have been drawn or not. That is, it is determined that whether the value of the index register j is equal to or more than the number B of the polygons constituting the i-th object or not. If the value of the index register j is equal to or more than the number B of the polygons constituting the i-th object, the process determining means 312 determines that all the primary polygons constituting the i-th object have been drawn.

[0079] If the process determining means 312 determines that all the primary polygons 110 constituting the object have not been drawn, control passes back to Step S7 for drawing another primary polygon 100, and generating and drawing secondary polygons 110a through 110c.

[0080] When all the primary polygons 110 constituting the object are drawn, control passes to Step S18. In Step S18, the value of the index register i is incremented by 1. Then, in Step S19, the process determining means 312 determines whether all the objects have been drawn or not. That is, it is determined that whether the value of the index register i is equal to or more than the number C of the objects or not. If the value of the index register i is equal to or more than the number C of the objects, the process determining means 312 determines that all the objects have been drawn.

[0081] If the process determining means 312 determines that all the objects have not been drawn, control passes back to Step S5 for performing the process of another object, i.e., drawing primary polygons 110, and generating and drawing secondary polygons 110a through 110c.

[0082] When all the objects are drawn, control passes to Step S20. In Step S20, the image displaying means 314 outputs image data drawn in the image memory 244 to the monitor 18 so that the outputted image data can be displayed on the screen of the monitor 18.

[0083] Then, in Step S21, the process determining means 312 determines whether there is a program ending request (game over, power off, etc.) to the image drawing means 300 or not. If there is not a program ending request, control passes back to Step S1 for repeating the subsequent steps.

[0084] As described above, according to the entertainment system 10 of the present embodiment, the new secondary polygons 110a through 110c corresponding to each of at least one primary polygon 11.0 constituting a three dimensional object are generated utilizing the light source 112 as a base point. Then, the front-side secondary polygon 110a selected from the secondary polygons 110a through 110c is drawn. Then, the remaining back-side secondary polygons 110b, 110c are drawn such that the color of the front-side secondary polygon 110a is eliminated. Accordingly, it is possible to easily generate shadow images of a plurality of objects in a complicated positional relationship, or generate a shadow image of an object having a complicated shape without using a stencil buffer or the like.

[0085] Since a shadow image is generated when the back-side secondary polygons 110b, 110c for partially eliminating the front-side secondary polygon 110a is drawn, it is no more necessary to draw semi-transparent polygons in a blackish color in the last step. Therefore, the number of processes can be effectively decreased.

[0086] In particular, according to the present embodiment, three-dimensional information concerning an object on which a shadow is projected (the spherical body in the example shown in FIG. 5A) is not necessary in drawing a shadow image. That is, information concerning two-dimensional images in an image memory and Z-buffer values for respective pixels of the two-dimensional images are only needed.

[0087] The image drawing method, the image drawing apparatus, the recording medium, and the program according to the present invention shall not be limited to the particular embodiment disclosed herein. It will be apparent to a person skilled in the art that numerous modifications and variation may be made without departing from the scope of the invention.

Claims

1. A method of drawing a shadow image of at least one primary surface (110) constituting a three-dimensional object (100), said method comprising the steps of:

    generating new secondary surfaces (110a, 110b, 110c) based on said primary surface (110) utilizing a light source (112) as a base point;
    drawing a first image of a front-side secondary surface (110a) selected from said secondary surfaces (110a, 110b, 110c); and
    drawing a second image of a back-side secondary surface (110b, 110c) selected from said secondary surfaces (110a, 110b, 110c),
    wherein said second image is drawn such that said first image is partially eliminated by said second image, thereby generating said shadow image of said primary surface (110).

2. An image drawing method according to claim 1, said method further comprising the step of;

drawing said primary surface (110) by rendering and hidden surface removal,
wherein said first and second images of said secondary surfaces (110a, 110b, 110c) are drawn by rendering and hidden surface removal.

3. An image drawing method according to claim 2, wherein a series of drawing processes performed in said steps of drawing said primary surface (110), generating said secondary surfaces (110a, 110b, 110c), and drawing said first and second images of said secondary surfaces (110a, 110b, 110c) are performed for every primary surface (110) constituting said three-dimensional object (100), thereby drawing an image of said three-dimensional object (100) and a shadow image (102) of said three-dimensional object (100).

4. An image drawing method according to claim 3, wherein when there are a plurality of primary surfaces (110, 120) constituting at least one three-dimensional object (100), said series of drawing processes are performed for every primary surface (110, 120) in order of distance from the remotest primary surface from said light source (112) such that a shadow image (116) of a primary surface (110) is drawn on another primary surface (120).

5. An image drawing method according to claim 3, wherein when there are a plurality of three-dimensional objects, said series of drawing processes are performed for every three-dimensional object in order of distance from the remotest three-dimensional object from said light source (112) such that a shadow image of at least one three-dimensional object is drawn on another three-dimensional object.

6. An image drawing method according to any one of claims 2 through 5, wherein Z-buffering is utilized in performing said hidden surface removal.

7. An image drawing apparatus comprising means (300) for drawing a shadow image of at least one primary surface (110) constituting a three-dimensional object (100), said means (300) for drawing a shadow image comprising:

means (306) for generating new secondary surfaces (110a, 110b, 110c) based on said primary surface (110) utilizing a light source (112) as a base point;
means (308) for drawing a first image of a front-side secondary surface (110a) selected from said secondary surfaces (110a, 110b, 110c); and
means (310) for drawing a second image of a back-side secondary surface (110b, 110c) selected from said secondary surfaces (110a, 110b, 110c),
wherein said second image is drawn such that said first image is partially eliminated by said second image, thereby generating said shadow image of said primary surface (110).

8. An image drawing apparatus according to claim 7, said means (300) for drawing a shadow image further comprising:

means (304) for drawing a primary surface (110) by rendering and hidden surface removal,
wherein said first and second images of said secondary surfaces (110a, 110b, 110c) are drawn by rendering and hidden surface removal.

9. An image drawing apparatus according to claim 8, said means (300) for drawing a shadow image further comprising means (312) for carrying out a series of drawing processes performed by said means (304) for drawing a primary surface (110), said means (306) for generating new secondary surfaces (110a, 110b, 110c), said means (308) for drawing a first image, and said means for generating a second image for every primary surface (110) constituting said three-dimensional object (100), thereby drawing an image of said three-dimensional object (100) and a shadow image (102) of said three-dimensional object (100).

10. An image drawing apparatus according to claim 9, said means (300) for drawing a shadow image further comprising means (302) for determining a drawing order when there are a plurality of primary surfaces (110, 120) constituting at least one three-dimensional object (100), wherein said drawing order is determined such that said series of drawing processes are performed for every primary surface (110, 120) in order of distance from the remotest primary surface from said light source (112), thereby drawing a shadow image (116) of a primary surface (110) on another primary surface (120).

11. An image drawing apparatus according to claim 9, said means (300) for drawing a shadow image further comprising means (302) for determining a drawing order when there are a plurality of three-dimensional objects, wherein said drawing order is determined such that said series of drawing processes are performed for every three-dimensional object in order of distance from the remotest three-dimensional object from the light source (112), thereby drawing a shadow image of at least one three-dimensional object on another three-dimensional object.

12. An image drawing apparatus according to any one of claims 8 through 11, wherein Z-buffering is utilized in performing said hidden surface removal.

13. A recording medium for recording a program and data for use of an image drawing apparatus (12) for drawing image data in an image memory (244) and outputting said image data drawn in said image memory (244) to a monitor (18) so that said outputted image data can be displayed on said monitor (18), said program comprising the steps of;

    generating new secondary surfaces (110a, 110b, 110c) based on said primary surface (110) utilizing a light source (112) as a base point;
    drawing a first image of a front-side secondary surface (110a) selected from said secondary surfaces (110a, 110b, 110c); and
    drawing a second image of a back-side secondary surface (110b, 110c) selected from said secondary surfaces (110a, 110b, 110c),
    wherein said second image is drawn such that said first image is partially eliminated by said second image, thereby generating said shadow image of said primary surface (110).

14. A recording medium according to claim 13, wherein said program further comprising the step of:

    drawing said primary surface (110) by rendering and hidden surface removal,
    wherein said first and second images of said secondary surfaces (110a, 110b, 110c) are drawn by rendering and hidden surface removal.

15. A recording medium according to claim 14, said program comprising a processing routine for carrying out a series of drawing processes performed in said steps of drawing said primary surface (110), generating said secondary surfaces (110a, 110b, 110c), and drawing said first and second images of said secondary surfaces (110a, 110b, 110c) for every primary surface (110) constituting said three-dimensional object (100), thereby drawing an image of said three-dimensional object (100) and a shadow image (102) of said three-dimensional object (100).

16. A recording medium according to claim 15, said program further comprising a processing routine for determining a drawing order when there are a plurality of primary surfaces (110, 120) constituting at least one three-dimensional object (100), wherein said drawing order is determined such that said series of drawing processes are performed for every primary surface (110, 120) in order of distance from the remotest primary surface from said light source (112), thereby drawing a shadow image (116) of a primary surface (110) on another primary surface (120).

17. A recording medium according to claim 15, said program further comprising a processing routine for determining a drawing order where there are plurality of three-dimensional objects, wherein said drawing order is determined such that said series of drawing processes are performed for every three-dimensional objects in order of distance from the remotest three-dimensional object from said light source (112) thereby drawing a shadow image of at least one three-dimensional object on another three-dimensional object.

18. A recording medium according to any one of claims 14 through 17, wherein said image drawing apparatus (12) comprises a Z-buffer (244b).

19. A program readable and executable by a computer for use of an image drawing apparatus (12) for drawing image data in an image memory (244) and outputting said image data drawn in said image memory (244) to a monitor (18) so that said outputted image data can be displayed on said monitor (18), said program comprising the steps of;

    generating new secondary surfaces (110a, 110b, 110c) based on said primary surface (110) utilizing a light source (112) as a base point;
    drawing a first image of a front-side secondary surface (110a) selected from said secondary surfaces (110a, 110b, 110c); and
    drawing a second image of a back-side secondary surface (110b, 110c) selected from said secondary surfaces (110a, 110b, 110c),
    wherein said second image is drawn such that said first image is partially eliminated by said second image, thereby generating said shadow image of said primary surface (110).

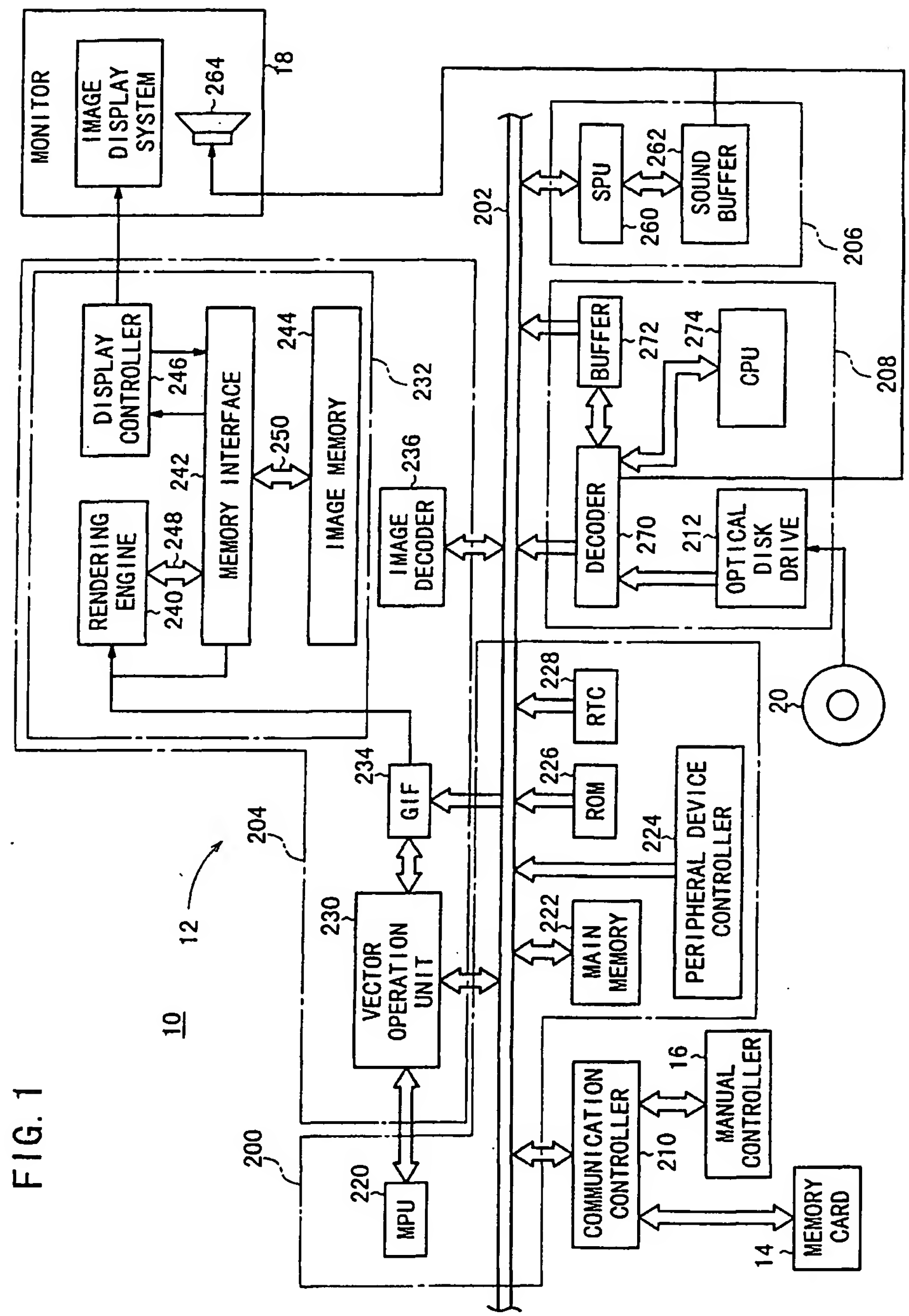

MONITOR
IMAGE DISPLAY SYSTEM
264
18
DISPLAY CONTROLLER
246
MEMORY INTERFACE
244
IMAGE MEMORY
232
242
250
RENDERING ENGINE
248
240
IMAGE DECODER
236
202
SPU
262
SOUND BUFFER
260
206
BUFFER
272
274
CPU
208
DECODER
270
212
OPTICAL DISK DRIVE
20
RTC
228
ROM
226
PERIPHERAL DEVICE CONTROLLER
224
MAIN MEMORY
222
GIF
234
204
12
VECTOR OPERATION UNIT
230
10
MPU
220
200
COMMUNICATION CONTROLLER
210
MANUAL CONTROLLER
16
MEMORY CARD
14

FIG. 1

FIG. 2

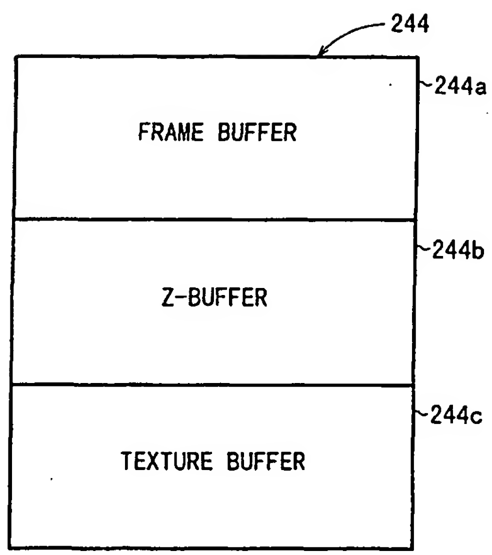


FIG.3

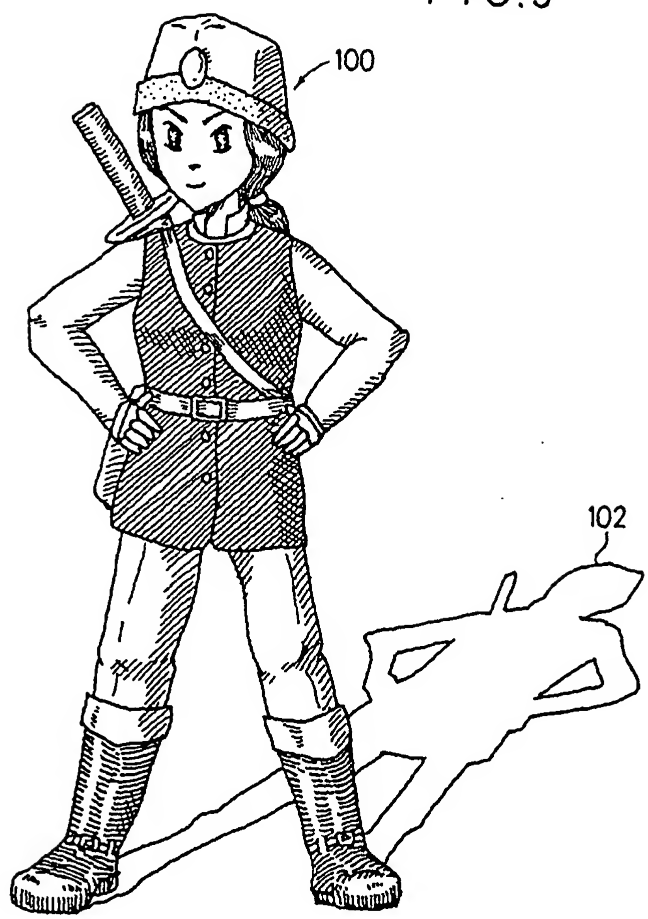


FIG. 4A

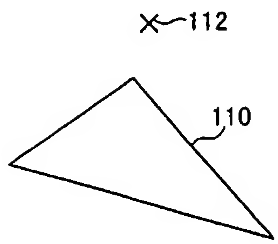


FIG. 4B

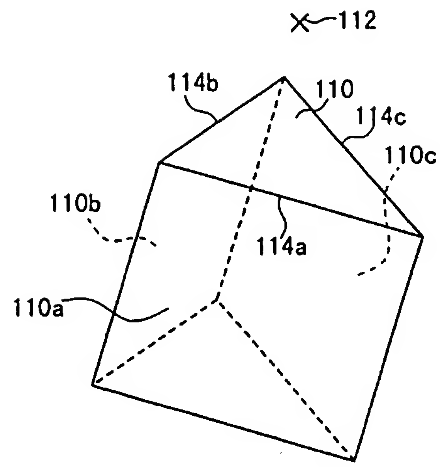


FIG. 4C

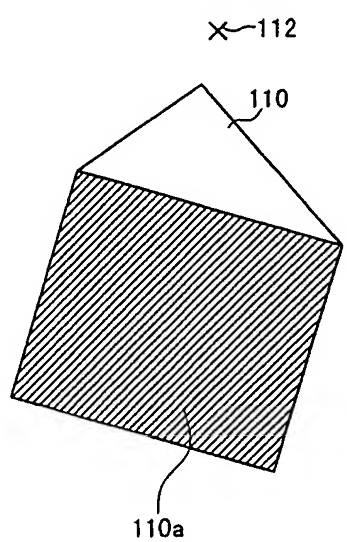


FIG. 4D

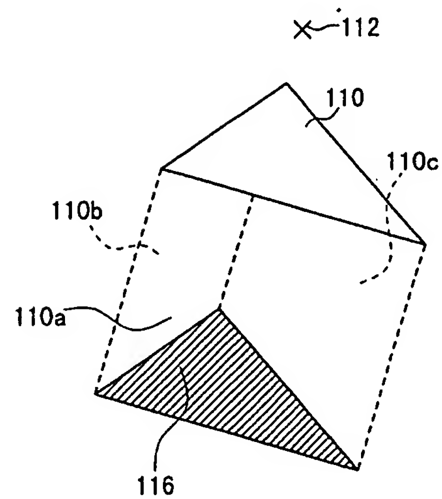


FIG. 5A

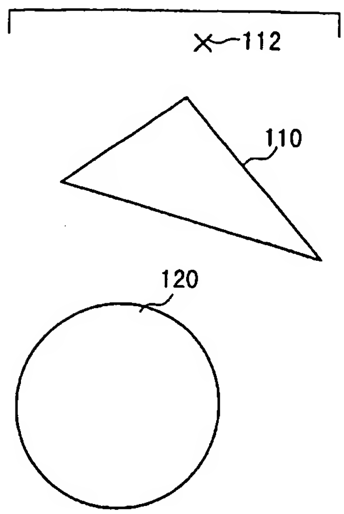


FIG. 5B

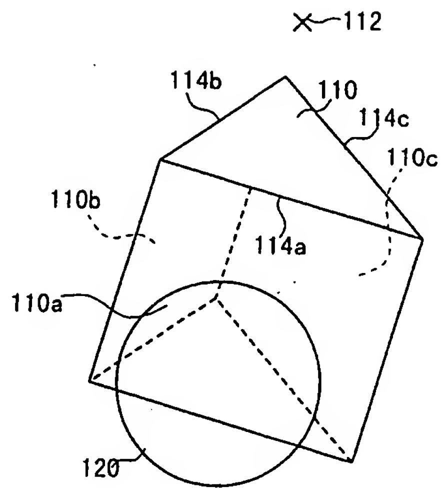


FIG. 5C

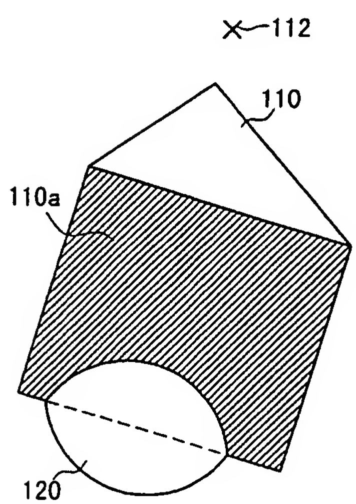


FIG. 5D

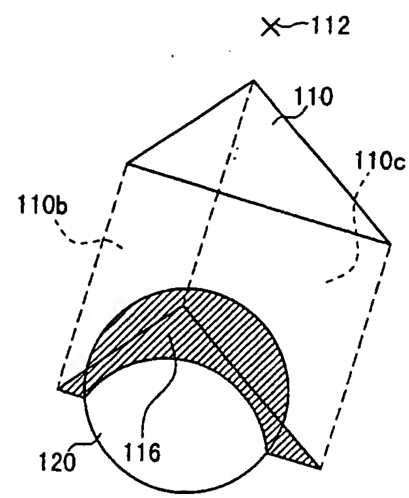


FIG. 6

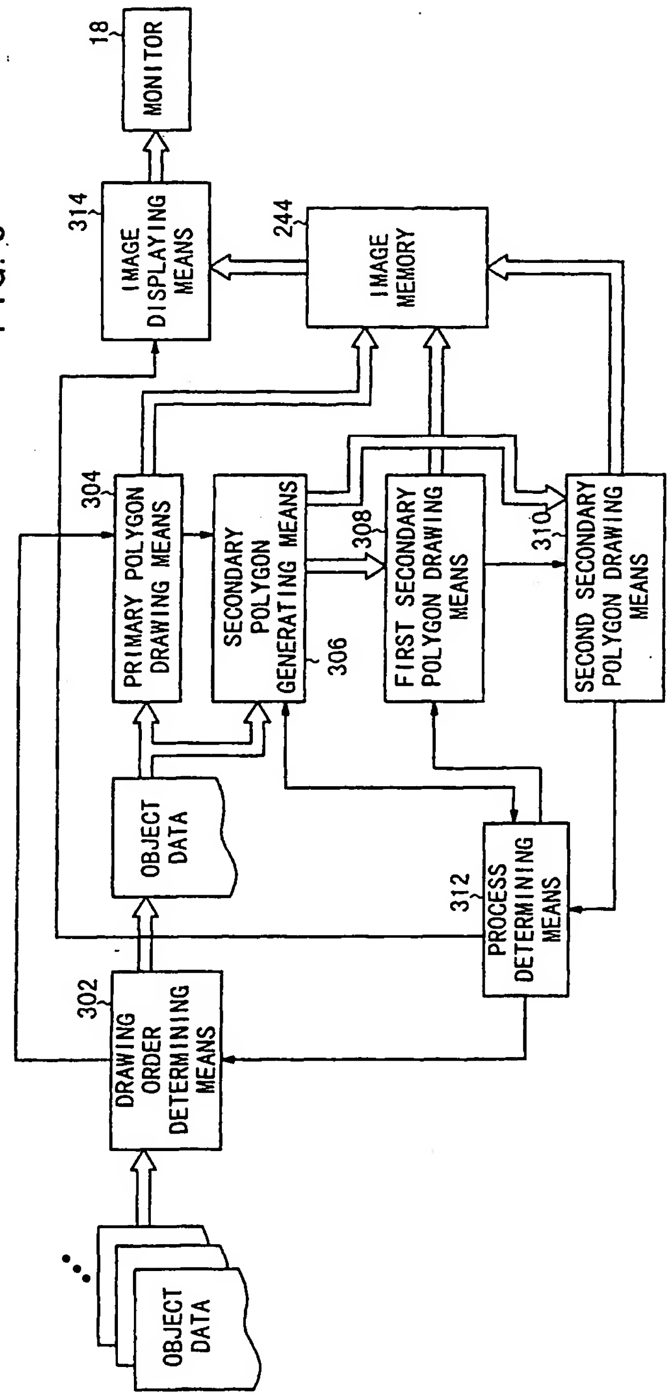

300
OBJECT DATA
DRAWING ORDER DETERMINING MEANS
302
OBJECT DATA
PRIMARY POLYGON DRAWING MEANS
304
SECONDARY POLYGON GENERATING MEANS
306
FIRST SECONDARY POLYGON DRAWING MEANS
308
SECOND SECONDARY POLYGON DRAWING MEANS
310
PROCESS DETERMINING MEANS
312
IMAGE MEMORY
244
IMAGE DISPLAYING MEANS
314
MONITOR
18

FIG. 7

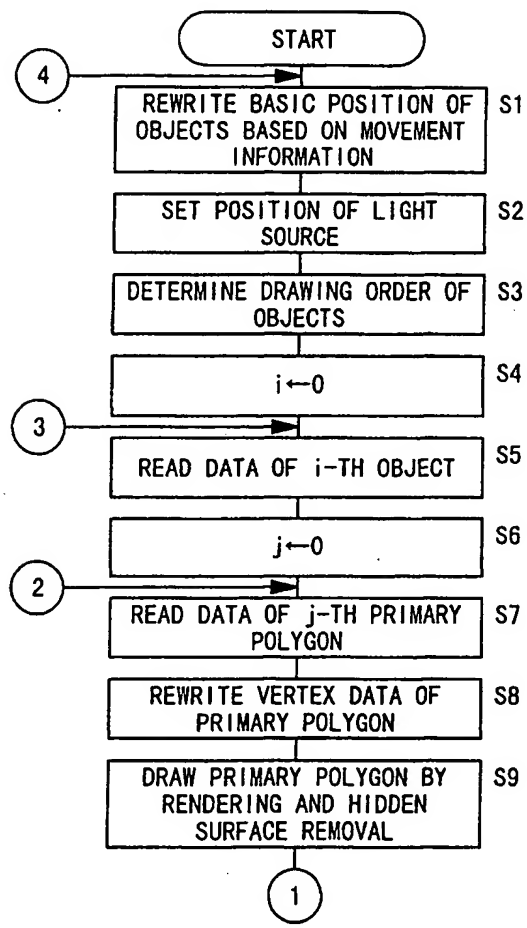
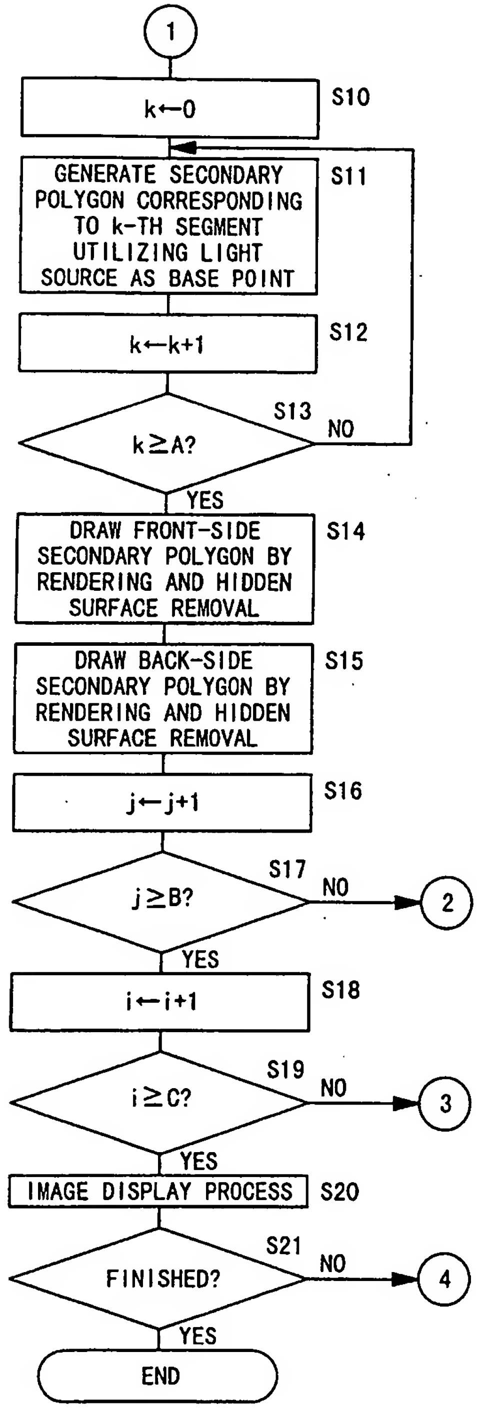

START
4
REWRITE BASIC POSITION OF OBJECTS BASED ON MOVEMENT INFORMATION
S1
SET POSITION OF LIGHT SOURCE
S2
DETERMINE DRAWING ORDER OF OBJECTS
S3
i←0
S4
3
READ DATA OF i-TH OBJECT
S5
j←0
S6
2
READ DATA OF j-TH PRIMARY POLYGON
S7
REWRITE VERTEX DATA OF PRIMARY POLYGON
S8
DRAW PRIMARY POLYGON BY RENDERING AND HIDDEN SURFACE REMOVAL
S9
1

FIG. 8


1
k←0
S10
GENERATE SECONDARY POLYGON CORRESPONDING TO k-TH SEGMENT UTILIZING LIGHT SOURCE AS BASE POINT
S11
k←k+1
S12
k≥A?
S13
NO
YES
DRAW FRONT-SIDE SECONDARY POLYGON BY RENDERING AND HIDDEN SURFACE REMOVAL
S14
DRAW BACK-SIDE SECONDARY POLYGON BY RENDERING AND HIDDEN SURFACE REMOVAL
S15
j←j+1
S16
j≥B?
S17
NO
2
YES
i←i+1
S18
i≥C?
S19
NO
3
YES
IMAGE DISPLAY PROCESS
S20
FINISHED?
S21
NO
4
YES
END